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Wavelet analysis of DNA sequences

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The Neuromuscular Response of the Soleus Following Whole Body Vibration

By

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ABSTRACT

The increase in muscle activity observed during whole body vibration (WBV) has been used as rationale for enhanced physical performance. However, no study has attempted to determine the mechanism whereby WBV alters muscle activity and performance. The purpose of this study was to assess whether spinal activity or contractile properties are altered following acute WBV at a frequency of 45Hz and amplitude of 2mm. H-reflex, M-waves and twitch contractile properties were measured prior to and following WBV. An isometric squat was maintained for 5, 1-minute vibration exposures and during recovery at 3,5,10,20,30 and 40 minutes. WBV inhibited H-reflex and M-wave amplitude by ~50% ($p<0.01$) and ~7% ($p=0.04$), respectively. Peak twitch tension decreased ~9.2% ($p=0.02$) and rate of force development was ~8.3% ($p=0.01$) slower. These data suggest that WBV might alter spinal activity through pre-synaptic inhibition, and that Ca^{2+} kinetics might be slowed in the contractile tissue.

CO-AUTHORSHIP STATEMENT

I certify that this thesis, and the research to which it refers, are the product of my own work, and that any ideas or quotations from the work or other people, published or otherwise, are fully acknowledged in accordance with the standard referencing practices of the discipline. I acknowledge the helpful guidance and support of my supervisors, Dr. Jennifer Jakobi and Dr. Kenji Kenno.

I hereby certify that the work embodied in this thesis is the result of original research and has not been submitted for a higher degree to any other University or Institution.

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I would first like to extend a very special thanks to my family for their support throughout my academic experience, without their encouragement this project would not have been possible. To all of the friends outside of school that have kept me motivated within the last year, I don't know where I would be without you.

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Finally, I would like to thank the two people that have meant the most to me throughout the duration of my undergraduate and graduate degree.

Reflecting back on my experiences, Dr. Kenji Kenno and Jenn Jakobi have taught me more than I could have hoped for. I have learned a variety of lessons outside of academia from you both and I feel as though I am a much better person for it. I truly want to thank you both for your patience, your guidance, and most importantly your friendship. I will never forget what you have done for me.

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LIST OF ABBREVIATIONS

1.	αmn:	Alpha motor neuron
2.	γmn:	Gamma motor neuron
3.	Ag/AgCl:	Silver/silver chloride electrode
4.	ANOVA:	Analysis of variance
5.	A/D:	Analog to digital
6.	B_r:	Baseline rest
7.	B_s:	Baseline standing
8.	C_s:	Control squat
9.	EMG:	Electromyography
10.	EMGrms:	Electromyography root mean square
11.	EPSP:	Excitatory post synaptic potential
12.	GABA:	Gamma aminobutyric acid
13.	H-reflex:	Hoffmann Reflex
14.	IPSP:	Inhibitory post synaptic potential
15.	MN:	Motor neuron
16.	MVC:	Maximum voluntary contraction
17.	M-wave:	Compound motor unit action potential
18.	Na^+-K^+:	Sodium – potassium
19.	Pt:	Peak tension
20.	SR Ca^{2+}:	Sarcoplasmic reticulum calcium
21.	TVR:	Tonic vibration reflex
22.	WBV:	Whole body vibration

Chapter I

Review of Literature

1.0 Introduction

Vibration can be characterized as an oscillatory mechanical input with a sinusoidal or non-sinusoidal predisposition. The vibration intensity can be directly related to the governing mechanical parameters of frequency generally expressed as a measure of oscillations per second (Hz), amplitude as the peak to peak displacement (mm), and magnitude as the resulting derivative of acceleration (Cardinale & Bosco, 2003). Occupational research has been the primary focus with respect to vibration due to the associated deleterious effects during long-term chronic exposure in the work place. However, recent progress in the scientific literature suggests that a controlled vibration stimulus may have practical neuromuscular and therapeutic implications.

The application of vibration as a training modality is a relatively new concept based on implications of potentially increased muscle strength and neuromuscular adaptations in the absence of morphological changes (Mester, Spitzenfeil, Schwarzer & Seifriz, 1999). In general, the neuromuscular improvements have been attributed to the enhancement of alpha motor neuron recruitment, an enhancement of the excitatory post synaptic potential (EPSP) response, synchronization, co-contraction of synergist muscles, and proprioceptor responses; however, these mechanisms remain equivocal (Cardinale & Lim, 2003). Vibration literature suggests that separate limb segments may be targeted through the use of individual vibrating hand-held

devices or an entire body influence may be elicited through a transcending vibration stimulus originating at the feet through a vibrating platform. Whole body vibration platforms generate a vertically oscillating stimulus in two distinctive ways 1) uniform oscillations in a vertical plane or 2) through reciprocating oscillations about a central axis with uniform vertical displacements (Cardinale & Rittweger, 2006) (Figure 1). Commercially available whole body vibration (WBV) training platforms commonly deliver frequencies between 15 – 60 Hz, amplitudes between 1 – 14 mm, and magnitudes from 1 – 15g (Cardinale & Rittweger, 2006).

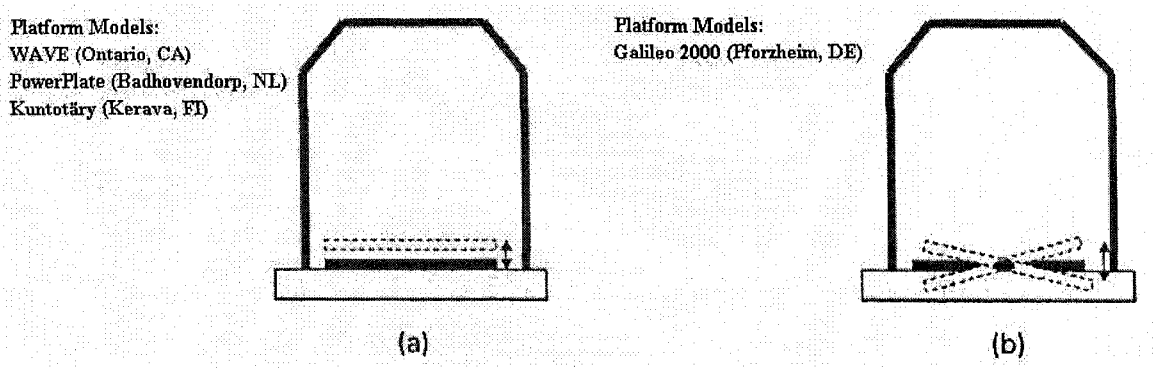

Figure 1. WBV platform types: (a) uniform oscillations in the vertical plane or; (b) reciprocating oscillations with varying vertical displacements about a central axis (Figure adapted from Cardinale & Rittweger, 2006).

1.1 Tissue Response

The premise behind enhanced neuromuscular adaptations, increased muscle strength and the associated benefits of WBV training are supported by the mass-spring properties of human muscle tissue. When mechanical vibration is applied to a muscle, the physical response of the tissue is characterized by fast and short changes in muscle length (Cardinale & Bosco, 2003) and these rapid changes are considered a neuromuscular phenomenon that effectively

modulates muscle stiffness to minimize soft-tissue vibrations (Cardinale & Lim, 2003).

It has been speculated this response is the direct result of the tonic vibration reflex (TVR); a response similar to the stretch reflex, however existing in a continuous loop without descending motor input (Eklund & Hagbarth, 1966; Jordan, Norris, Smith, & Herzog, 2005). The TVR however, is traditionally elicited through direct controlled vibration of a tendon complex at frequencies (100-200 Hz) exceeding the general range associated with WBV research. The TVR as applied to WBV constitutes a neural circuitry which includes both monosynaptic and polysynaptic projections within the spinal cord (Figure 2).

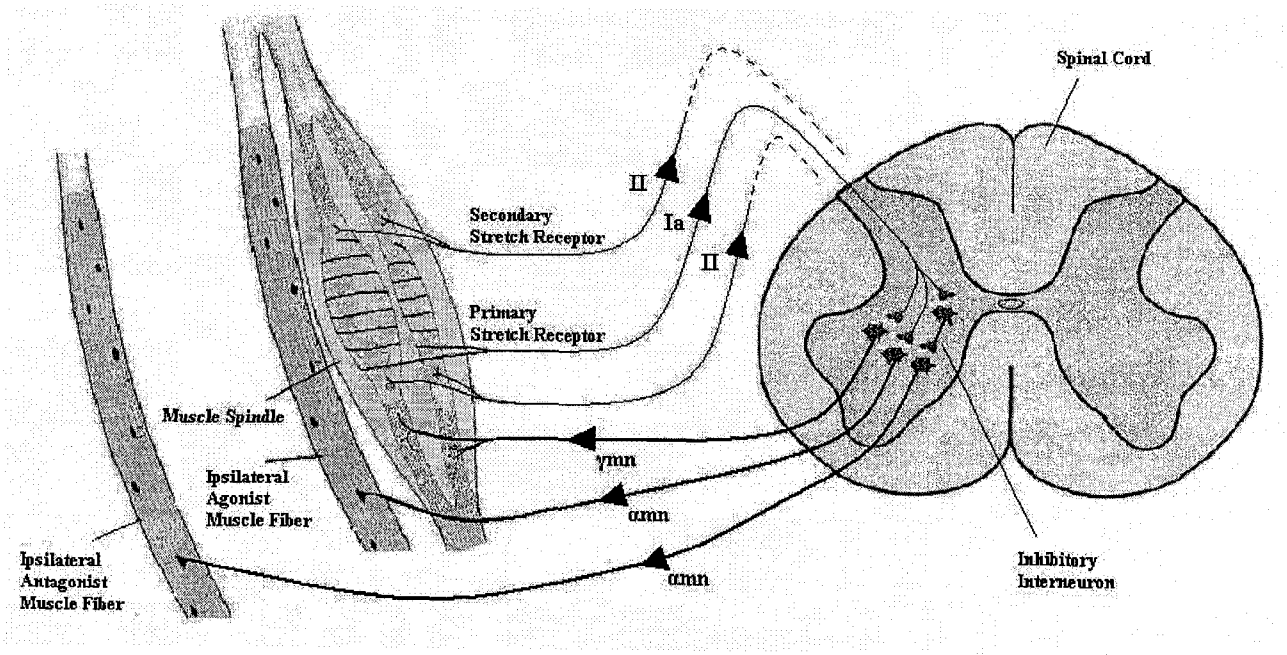

Figure 2. TVR diagram: a proposed reflexive contraction to the perturbation of WBV. Primary stretch receptors of the muscle spindle respond to changes in muscle length due to WBV and propagate length changes primarily via the Ia afferent sensory signals and some by the secondary stretch receptors to the spinal cord. The direct result is the co-activation of the ipsilateral agonist muscle fiber by the αmn and resetting of the stretch receptors by the γmn, followed by simultaneous reciprocal inhibition of the ipsilateral antagonist muscle by its αmn. The dashed afferent (II) neural projection represents low level sensitivity (Figure adapted from http://www.partnersinfitness.com; Berne & Levy, 1993).

It is proposed that during WBV the primary stretch receptors (type Ia afferent) within the muscle spindles are more sensitive to a vibration stimulus than the secondary (type II afferent) or even golgi tendon organs (Cardinale & Bosco, 2003). They send information primarily via the 1a afferents encapsulated in a mixed nerve back to the spinal cord where it branches to make three synaptic connections (Figure 2). The 1a afferent may synapse monosynaptically and polysynaptically creating an excitatory postsynaptic potential (EPSP) that results in the co-activation of the ipsilateral agonist muscle fiber by the αmn and resetting of the stretch receptors by the γmn. In addition, a polysynaptic projection with an inhibitory interneuron produces an inhibitory post synaptic potential (IPSP) within the ipsilateral antagonist αmn to compliment the reflexive agonist contraction.

1.2 WBV Performance Influence

Given the reflexive neuromuscular nature of WBV in contrast to skeletal muscle morphological changes seen with standard resistance training methods, a number of different acute and chronic WBV experimental protocols have been investigated. WBV protocols have been specifically designed with the intent of improving isometric and dynamic performance measures related to sports and daily activities.

1.3 Isometric WBV Protocols

To evaluate the effect of vibration training on skeletal muscle performance, Bosco, Cardinale & Tsarpela (1999a) used a vibrating dumbbell (Galileo 2000, Pforzheim, DE) set at 30 Hz and 6 mm deflection during 5

isometric bicep brachii contractions lasting 60 seconds with equivalent rest periods. They reported that with the addition of vibration training, there was a significant increase in bicep brachii mechanical power (Figure 3A). They also reported a decrease in the EMG/power ratio after the vibration training (Figure 3B). It was speculated the decrease in the EMG/power ratio was a result of an increase in neuromuscular efficiency relative to global muscle activation giving rise to the observed increase in mechanical power.

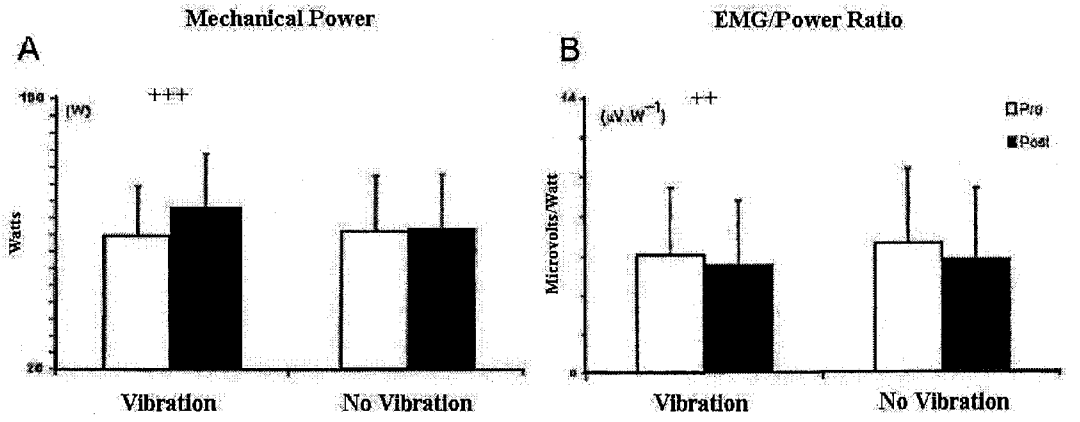

Figure 3. Average mechanical power and EMG/power ratio recorded during isometric arm flexion. (A) Mechanical power in vibration and no vibration group pre and post vibration training expressed in watts; (B) EMG/power ratio in vibration and no vibration group pre and post vibration training expressed in microvolts per watt. (+++ $P < 0.001$, ++ $P < 0.01$) (Figure adapted from Bosco et al. 1999a).

Bosco, Colli, Introini, Cardinale, Tsarpela, Madella, Tihanyi & Viru (1999b) examined the effect of WBV (Galileo 2000, Pforzheim, DE) training at 26 Hz and 10 mm during 10 isometric contractions at 100° knee flexion for 60 sec followed by 60 sec rest intervals. They reported that relative to dynamic leg press performance measures prior to the WBV training; the lower leg muscles demonstrated a significant increase in the average voluntary force production, contraction velocity and power.

In contrast, a 9 day study conducted by Cochrane, Legg & Hooker (2004), studied the effect of using 2 minutes of WBV training (Galileo 2000, Pforzheim, DE) at 26 Hz and 11 mm followed by 40 second rest intervals at 5 different isometric leg positions. Post-WBV performance measures exhibited no significant differences in the countermovement jump, squat jump, varied sprint testing, or agility testing.

Improved performance indices have been induced through the incorporation of vibration and have been credited primarily to neuromuscular as opposed to morphological adaptations (Bosco et al. 1999a; Roelants, Delecluse & Verschueren, 2004a). Differences in the performance measures may be attributed to subtleties with respect to the parameters associated with isometric vibration training or in the entire protocol itself. As an example, Bosco et al. (1999a,b) administered acute vibration training bouts in a single session as opposed to a series over multiple sessions to elicit favorable performance results. The equivocal nature of the WBV literature with respect to isometric protocols and performance measures has led to the inclusion of dynamic movements in acute and chronic protocols.

1.4 Combined Isometric and Dynamic WBV Protocols

With the intent of maximizing performance measures, investigators have examined combined protocols using static and dynamic WBV training. Cochrane & Stannard (2005), characterized the acute effect of 26 Hz and 6 mm (Galileo 2000, Pforzheim, DE) on the counter movement jump, and a sit and reach test.

WBV training significantly increased both the counter movement jump (8.1 ± 5.8%) and the sit and reach task (8.2 ± 5.4%).

Similarly, Roelants et al. (2004a) examined postmenopausal females in a 24 week WBV training program using static and dynamic squats and lunges. They reported comparable performance gains between WBV and a traditional resistance training protocol in isometric strength (12.4%; 16.8%), dynamic strength (12.1%; 12.5%), and vertical jump (16.0%; 12.1%). They speculated the improved performance measures were a consequence of post WBV neural potentiation and the added eccentric stimuli WBV provides relative to a control.

In a follow up study with a similar protocol, Roelants, Delecluse, Goris & Verschueren (2004b) evaluated knee extension force following WBV. They reported significant increases in isometric (24.4% ± 5.1%) and isokinetic (7.2% ± 2.6%) knee extension force. From their research Roelants et al. (2004a,b) suggested that WBV training may represent an efficient alternative to traditional resistance training in pursuit of increased knee extension performance.

Another recent study conducted by Rittweger, Mutschelknauss & Felsenberg (2003) investigated the facilitation of the patellar tendon stretch reflex response to WBV. Using a vibration stimulus of 26 Hz and 6 mm (Galileo 2000) subjects performed a loaded dynamic squat with 40% body mass until exhaustion. They reported the patellar tendon reflex amplitude following WBV training to be significantly increased relative to a control and an initial pre-vibration test. They speculated the facilitated patellar tendon reflex was the result of an enhanced αmn excitability (Rittweger et al., 2003).

Collectively WBV studies using both isometric and dynamic protocols have demonstrated a general trend that WBV does result in functional performance increases. These improvements may be the result of the autogenic tissue response associated with vibration training and the potential reflexive muscular influence exhibited. In addition to functional improvements, vibration has also been observed to result in a concomitant increase in muscle activity, as confirmed by Delecluse, Roelants, & Verschueren (2003).

1.5 Muscle Activity

While the practical benefits of WBV are equivocal, research has begun using surface electromyography (EMG) to indirectly examine the effect of WBV on global muscle activity. In a 12 week study by Delecluse et al. (2003), young females performing static and dynamic knee extensor exercises during WBV (Powerplate, Badhovendorp, NL) at 35–40 Hz and 2.5–5 mm demonstrated significant increases in the countermovement jump (7.6 ± 4.3%) as well as isometric (16.6 ± 10.8%) and dynamic knee extensor torque (9.0 ± 3.2%). EMG data collected from the medial gastrocnemius provides an illustration of the increase in muscle activity due to WBV (Figure 4).

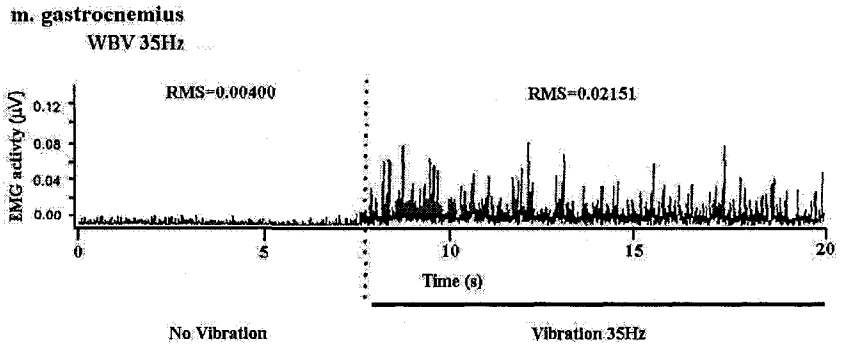

Figure 4. EMGrms response (mV) of the medial gastrocnemius recorded in a static half squat position. Dotted line represents the onset of WBV at 35 Hz and 5 mm (Figure adapted from Delecluse et al. 2003).

With respect to the signal processing, EMG root mean square (EMGrms) is an effective means of evaluating muscle activity by providing a linear envelope corresponding to positive mean electrical activity. Consequently, a mean value of muscle activity can be obtained for examination or comparison. This study as well as others, has confirmed through EMG that static and dynamic WBV exercises results in an increase in skeletal muscle activity to accompany increased performance measures (Bosco et al. 1999a; Cardinale & Lim, 2003; Rittweger et al. 2003; Torvinen, S., Kannus, P., Sievanen, H., Jarvinen, T.A., Pasanen, M., Kontulainen, S., Jarvinen, T.L., Jarvinen, M., Oja, P., & Vuori, I., 2002a; Torvinen, S., Sievanen, H., Jarvinen, T.A., Pasanen, M., Kontulainen, S., & Kannus, P., 2002b).

Recently, Hazell, Jakobi & Kenno (2007), attempted to determine the optimal frequency and amplitude that would elicit the greatest changes in EMG. Male subjects were exposed to 30 second trials with 5 minute rest intervals while performing a static semi-squat position and a dynamic squat on a WBV platform (WAVE, Ontario, CA) ranging from 25 – 45 Hz and either 2 – 4 mm. EMG data was collected and the EMGrms evaluated on the vastus lateralis and quadriceps of the lower leg. Hazell et al. (2007) reported the greatest significant increases in quadriceps muscle activity at 45 Hz and 2mm (6.7%) and 45Hz and 4mm (8.7%) during the static and dynamic movements respectively.

The increase in EMG during WBV is an indirect measure of muscle activity but does not indicate how WBV might be facilitating an acute or chronic neuromuscular adaptation that improves performance. The WBV neuromuscular

improvements may reflect an increase in alpha motor neuron recruitment, an enhancement of the excitatory post synaptic potential (EPSP) response, synchronization, co-contraction of synergist muscles, and/or proprioceptor responses. To more clearly understand what influence WBV may have on increased muscle performance, the underlying neural mechanism necessitates evaluation. It has been postulated that the significance and contribution of the reflexive mechanism could be tested through observing changes in the evoked response of Hoffmann's reflex, a traditional means of isolating and assessing neural potentiation (Cardinale & Bosco, 2003).

1.6 Hoffmann's Reflex

While the reported increases in EMG are interesting they still represent an indirect measure of global skeletal muscle activity and provide little insight into the neurological mechanisms that WBV may be inducing to result in improvements in performance. Given that WBV may be evoking the TVR, WBV might be facilitating an increase in spinal reflex excitability, subsequently enhancing the EPSP response resulting in performance increases. It has been postulated (Cardinale & Bosco, 2003) that the contribution of the reflexive mechanism could be tested by observing for changes in the parameters of what is termed the Hoffmann reflex (H-reflex). The H-reflex is considered a means of experimentally assessing alpha motor neuron (αmn) recruitment within the spinal cord following the percutaneous stimulation of a mixed nerve of a selected muscle (Schieppati, 1987). Most research has been conducted using the soleus muscle due to its reliability, convenience, and accessibility with respect to

effective H-reflex recordings (Hopkins, Ingersoll, Krause, Edwards, & Cordova, 2001). When the tibial nerve is stimulated an H-reflex is evoked and the initial response (Figure 6, symbol a) is the excitation of the 1a afferent sensory axon with signal propagation toward the spinal cord.

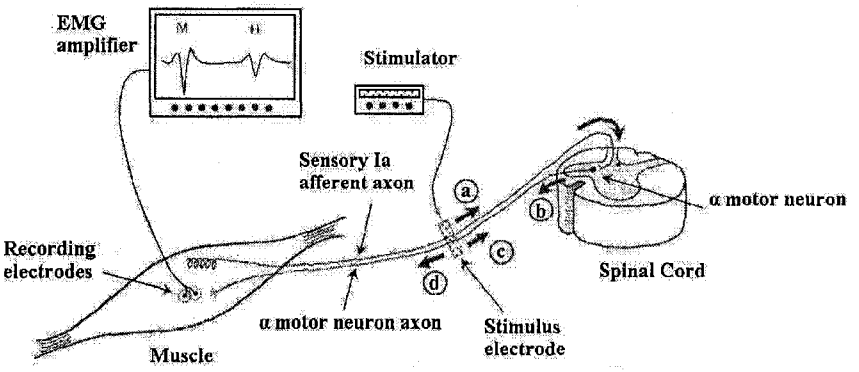

Figure 5. Schematic representation of an idealized setup to record the H-reflex. Refer to text for a descriptive explanation of the H-reflex setup (Figure adapted from Aagaard, Simonsen, Andersen, & Dyhre-Poulsen 2002).

Simultaneously there is excitation of the αmn within the mixed nerve which propagates in two directions: 1) toward the muscle (Figure 5, symbol d) provided the stimulation intensity exceeded the threshold of the αmn generating a recordable M-wave through surface EMG and 2) a signal traveling back toward the spinal cord (Figure 5, symbol c). The retrograde αmn signal (Figure 5, symbol c) collides with the reflexive EPSP sensory response (Figure 5, symbol b) which is the result of the excitation of the 1a afferent sensory axon synapsing in the spinal cord with the alpha motor neuron and generating the EPSP. Due to the collision of the two signals traveling in opposite directions, there is a partial cancellation of the initial response (Figure 5, symbol b) which results in the propagation of an attenuated signal toward the agonist muscle (Aagaard et al.,

2002). As a result, the attenuated signal is recorded as an H-reflex with a latency of 30-40 ms after the initial M-wave (Aagaard et al., 2002).

The amplitude of the H-reflex is however dependent on the percutaneous stimulation intensity of the selected mixed nerve. For example, when a low intensity percutaneous stimulation is applied, the initial tissue response is the selective depolarization of Ia sensory afferent neurons followed by signal propagation toward the spinal cord (Aagaard et al., 2002). The stimulation will give rise to an H-reflex of the activated muscle with no M-wave preceding it (Figure 6 symbol A). This selective depolarization of Ia sensory afferent neuron is the result of its large axon diameter and lower axial resistance which allows for excitation to occur at lower stimulus intensity (Enoka & Fuglevand, 2001). As a result, this property gives rise to the inverse relationship between stimulation intensity and H-reflex amplitude (Figure 6).

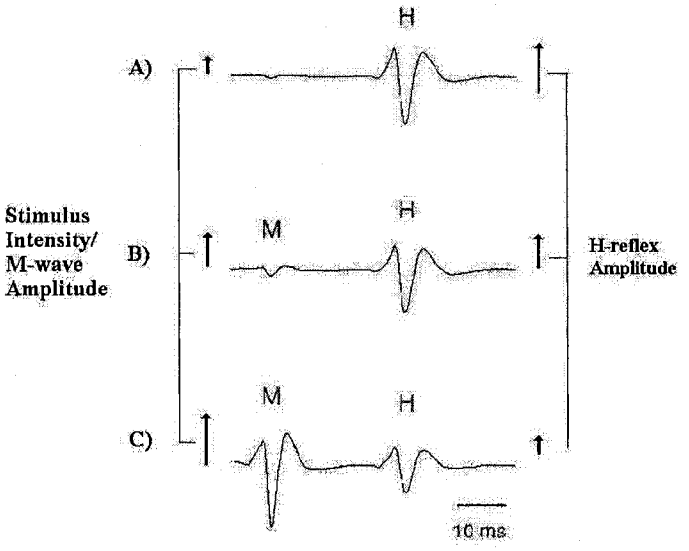

Figure 6. Illustration of dependence on stimulus intensity and the resulting H-reflex amplitude. A) Low level stimulation giving rise to little or no M wave (silent period) followed by an H-reflex response. B) Increase in stimulation intensity producing an M-wave followed by a smaller H-reflex response. C) Further increase in stimulation intensity produces a large M-wave and small H-reflex. (Figure adapted from Aagaard et al., 2002).

However, to be able to properly characterize the H-reflex response experimentally, it must be preceded by a submaximal M-wave. Therefore, the key experimental criteria for reliable evaluation of the H-reflex, is to monitor and ensure the constant amplitude of a submaximal M-wave prior to the H-reflex. This is performed due to M-wave amplitude dependence on stimulation whereas the H-reflex amplitude may be influenced by a variety factors that are not easily controlled. The M-wave elicited will then be followed by an H-reflex with an amplitude that is dependent upon the resultant collision between the retrograde alpha MN (Figure 5, symbol c) and the reflexive EPSP sensory response (Figure 5, symbol b)

The H-reflex is evaluated by directly measuring the peak amplitude, the H-reflex/M-wave amplitude ratio, and the latency time period for the H wave (Figure 7). The amplitude (Figure 7, symbol a) and H-reflex/M-wave amplitude ratio are both indicative of the efferent volley magnitude, following signal collision, back to the muscle. The latency period (Figure 7, symbol b) signifies the delay in time it takes to measure a response from the stimulus artifact; it is directly proportional to the proximity of the muscle to the spinal cord.

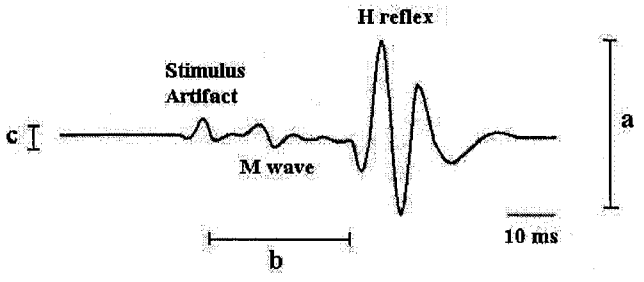

Figure 7. Approximation of a detailed electromyographic H-reflex preceded by a stimulus artifact and M-wave. a) H-reflex amplitude measured as peak to peak distance; b) Latency period measured as the time duration between the artifact and H-reflex onset; c) M wave amplitude (Figure adapted from Misiaszek, 2003).

1.7 H-Reflex Literature

Alrowayeh, Sabbahi & Etnyre (2005) evaluated changes in the H-reflex in the soleus and vastus medialis while standing at various static knee angles. Subjects stood in an isometric semi-squat position at knee angles of 0, 30, 45, and 60° while a recording of the H-reflex was taken. They reported that relative to 0, 30 and 45°, the H-reflex exhibited a linear decrease in amplitude as knee angle increased. However at 60° the H-reflex amplitude increased to show a possible trend that a further increase in angle may facilitate a greater response relative to the 0° knee angle. Similarly an incremental increase of the H-reflex within the vastus medialis was found with increasing knee angle. However, due to the confounding factors of the vastus medialis including the proximity to the spinal cord, branching of the femoral nerve, varying amounts of subcutaneous tissue, different ratios of efferent to afferent fibers, as well as the presence of an F-wave, the vastus medialis H-reflex is more difficult to measure and therefore less reliable for evaluation (Hopkins et al., 2001).

Aagaard et al., (2002) were interested in determining whether the H-reflex was altered during a 14 week resistance training program involving heavy dynamic weight lifting exercises of the lower leg. They reported that the H-reflex within the soleus muscle demonstrated a linear increase over time to effectively substantiate the theory that resistance training could result in a spinal-neuronal adaptation. They suggested that the increase in H-reflex amplitude due to resistance training was a result of a training-induced modification of the spinal

reflex possibly due to an enhanced supraspinal input, motoneuronal excitability, or decreased presynaptic inhibition (Aagaard et al., 2002).

Collectively, acute conditioning with WBV has been observed to produce functional enhancements with respect to performance measures and a concomitant increase in muscle activity. These changes following WBV have been speculated to be the result of adaptations in spinal reflex excitability which might be reflected in an increase in alpha motor neuron recruitment and the EPSP response. Research has confirmed that changes in the alpha motor neuron pool can be identified following a training stimulus by the evaluation of the H-reflex. Neuromuscular research has also confirmed that the contribution of a muscle response to the benefits of WBV can be simultaneously distinguished through the assessment of twitch contractile properties.

1.8 Purpose

I. To quantify the influence of whole body vibration during a static semi-squat on the neuromuscular response of the soleus as characterized by the latency, amplitude, and H/M ratio of Hoffmann's reflex.

II. To concurrently quantify the effect of acute isometric whole body vibration training on the twitch contractile properties of the soleus.

III. To evaluate plantar flexion and dorsi flexion maximum voluntary contractions (MVC) with the inclusion of the twitch interpolation technique as an absolute measure of performance.

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Chapter II

Manuscript

2.0 Introduction

Acute and chronic whole body vibration (WBV) exposure reportedly increases muscle performance(Bosco, Cardinale & Tsarpela, 1999a; Bosco, Colli, Introini, Cardinale, Tsarpela, Madella, Tihanyi & Viru, 1999b; Cochrane, Legg & Hooker, 2004; Cochrane & Stannard, 2005; Rittweger, Mutschelknauss & Felsenberg, 2003; Roelants, Delecluse, Goris & Verschueren, 2004b) However, there has been no attempt to quantify the mechanisms responsible for either the enhanced muscle activity and/or increases in performance following WBV. Increases in spinal reflex excitability have been hypothesized (Cardinale & Lim, 2003) as the primary contributing physiological mechanism. An altered spinal excitability was indirectly supported by Rittweger et al's (2003) observation of an enhanced patellar tendon stretch reflex activity following WBV exposure. In order to better interpret the performance benefits reported with WBV and to develop WBV training paradigms, the underlying spinal mechanisms responsible for the increase in muscle performance associated with WBV warrant investigation.

The Hoffman Reflex (H-reflex) amplitude is an experimental means of detecting and examining for changes in spinal reflex excitability (Schieppati, 1987). Prior studies have utilized the H-reflex and through controlled changes in vibration amplitude have determined that muscle length and resistance training influence 1a afferent feedback (Aagaard, Simonsen, Andersen, Magnusson, &

Dyhre-Poulsen, 2002; Alrowayeh, Sabbahi & Etnyre, 2005). It has been suggested that the response induced by WBV is analogous to the tonic vibration reflex (TVR) (Cardinale & Lim 2003) where sequential rapid alterations in muscle length enhance 1a afferent feedback and induce reflexive contractions of the homonymous muscle through monosynaptic projections in the spinal cord (Eklund & Hagbarth, 1966; Jordan, Norris, Smith, & Herzog, 2005). The integrity of this loop is often explored through measures of H-reflex amplitude.

Additionally the compound muscle action potential (M-wave) generated via percutaneous stimulation prior to H wave formation indicates selective recruitment of the alpha motor neuron and the integrity of the neuromuscular junction relative to afferent feedback following WBV exposure. The relationship between WBV, the process of neuromuscular transmission, and muscle activation has yet to be established through parameters of the M-wave. As well, contractile activity coinciding with the properties of peak twitch tension, and the average rate and relaxation of twitch force development may provide further resolution to the effect of intracellular calcium kinetics on the function of excitation contraction coupling following WBV.

The purpose of this study was to quantify the influence of acute WBV on spinal reflex excitability and tibial nerve conduction velocity through measurement of the H-reflex and M-wave. Twitch properties were examined as well in order to differentiate the involuntary contractile response of the muscle from spinal reflex excitability relative to observed changes in performance. Maximum voluntary contractions (MVC) were utilized as a measure of

performance through plantar flexion and dorsi flexion with the inclusion of the twitch interpolation technique to ensure maximal efforts on each attempt. As well, muscle activity was documented simultaneous to WBV exposure during isometric squats in an attempt to correlate a functional increase in EMG with performance.

2.1 Methods

Subjects

Eight young males (24 ± 2yrs) and eight young females (23 ± 2yrs) participated in this study. Young males were taller (187 ± 5cm) and heavier (96 ± 18kg) than the young females (163.5 ± 3cm; 58 ± 4kg). Subject exclusion criteria consisted of any standard contraindication to WBV; neuropathy, myopathy, cardiovascular disease, epilepsy, gallstones, kidney stones, joint problems/implants, recent thrombosis, acute inflammation, lower back problems, intense migraines, recent operative wounds, cancer, and pregnancy. Also, persons participating in planned exercise sessions 3 times or more per week were excluded from the study. Informed written consent (Appendix A) was obtained upon recruitment and all procedures were approved according to the local University ethics board (Appendix B) conforming to the Declaration of Helsinki.

2.2 Experimental Setup & Protocol

Subjects were seated in an ergonomic car seat mounted on a modified hydraulic jack allowing for adjustment in the vertical and horizontal plane. Directly in front of the chair was a fixed unilateral foot dynamometer positioned

appropriately for the non-dominant leg. Subjects were seated with hip and knee angle positioned and maintained at 90° flexion through chair and dynamometer adjustments and verbal reminders to maintain an upright posture where the back and neck rested against the chair during experimental procedures were given. The ankle angle was positioned to 10° plantar flexion and the foot was fastened with two velcro straps to the isometric plantar flexion and dorsi flexion dynamometer. Attached to the underside of the foot plate of the dynamometer was a linear calibrated force transducer (Transducer Techniques, Temecula, CA).

Adjacent to the dynamometer (1.5m) was a vertical vibration platform (WAVE™, Ontario, CA). When on the platform knee angle was 60° flexion, and this position was monitored through experimenter observation and via real-time joint feedback measures from a goniometer (DataLog, Biometrics, Ruther Glen, VA) that was attached to the lateral side of the non-dominant leg with the output device fastened to a waist-belt. Feet were positioned on heel markers that were set to be shoulder width apart for all subjects. Ankle and hip angle were maintained in a comfortable position based upon foot position and knee angle. Consistency was maintained within and between trials through visual experimenter observation and verbal feedback.

Stimulation

A conductive 5 x 2.5cm carbon-carbon rubber stimulating electrode (cathode) was placed in the popliteal fossa and a second electrode (5 x 2.5cm) placed 1cm distal. Both electrodes were secured to the skin with transpore tape.

Single electrical pulses were elicited with increases in intensity until a plateau was observed in M-wave. Subsequently, the appropriate submaximal intensity for H-Reflex stimulation was resolved by progressively decreasing stimulation intensity in 10 mA decrements from supramaximal intensity until peak H-reflex amplitude was obtained.

Protocol

A familiarization protocol was performed to acclimate subjects to the sensation of WBV. This protocol involved maintaining an isometric squat position on the vibration platform where sequential exposures of increasing frequency and amplitude (25Hz;2mm, 35Hz;2mm and 45Hz;2mm) were provided for 30s with 60 second intervals between progressions All participants reported no adverse feelings of WBV and were comfortable with the maintenance of the isometric squat position.

Subjects performed three maximum voluntary dorsi flexion and plantar flexion contractions (MVC). All subjects were given identical scripted instructions and strong verbal encouragement by the primary investigator. MVC contractions were 5 seconds in length with 30 seconds of rest between each trial. The MVC contraction was verbally cued and supramaximal twitches were evoked before, during and after the plantar flexion attempt to assess central drive with the twitch interpolation technique. Activation was assessed similar to prior experiments [(1-superimposed twitch mean peak torque/post twitch peak torque)*100] with double pulses at 200V with a 100μs pulse duration where intensity was defined as the necessary current to elicit a supramaximal M-wave response (Jakobi &

Rice, 2002; Scherer, Edwards & Jakobi, 2007). Assessment of dorsi-flexion MVC was not made with the twitch interpolation technique; the highest force attained from the 3-4 dorsi-flexion contractions was utilized as maximal performance. Following assessment of MVCs, three H-reflexes were elicited, followed by three M-waves and lastly three H-reflexes repeated. This stimulation protocol was repeated at pre-determined times during the WBV protocol (Figure 8).

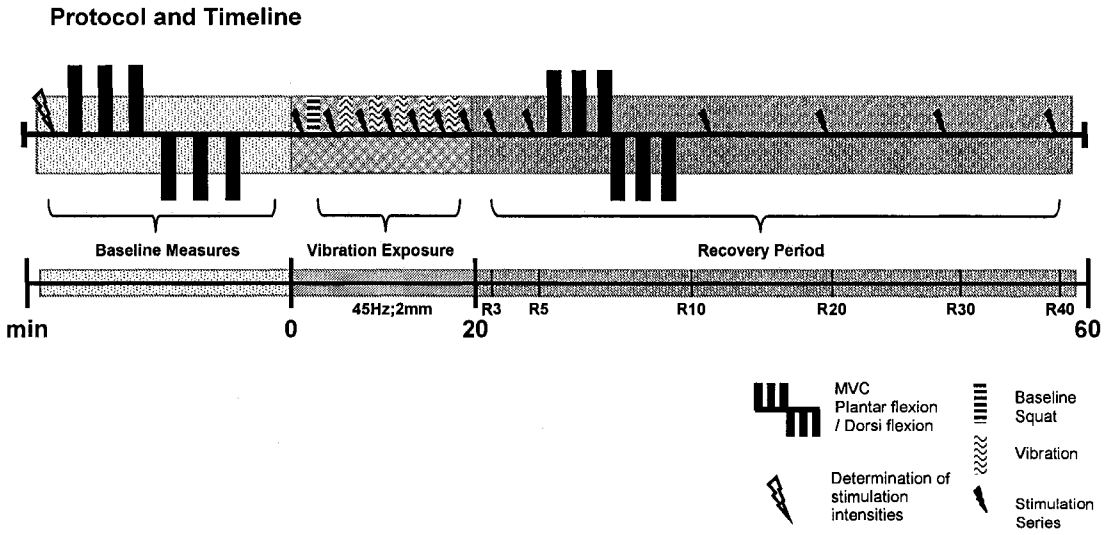

Figure 8. Experimental protocol and the corresponding timeline. Baseline measures consist of resolving stimulation intensity necessary to evoke the H-reflex and M-wave. Subsequently dorsi flexion and plantar flexion MVC were attempted. The vibration exposure consisted of a series of baseline stimulation measures (Br), **a control squat with no vibration and subsequent assessment of M-wave and H-reflexes** (Br). **Following baseline assessment the isometric squat during WBV followed by H-reflex and M-wave assessment were repeated five times in succession. The stimulation protocol was employed 30s after each 60-sec WBV squat. The inter-vibration interval was three minutes The recovery period consisted of stimulation to evoke the H-reflex and M-wave at R3, R5, R10, R20, R30, and R40 minutes following the last squat and MVC were performed at R6.**

The first series of stimulation measures were conducted at baseline prior to any interaction with the platform (baseline rest; B_R), (Figure 8) the second series of baseline measures were elicited subsequent to 60 seconds of standing on the platform in a squat position with no vibration (baseline standing; B_S).

Following baseline assessment of H-reflex and M-wave activity, the WBV protocol was initiated (Figure 8), where 5 periods of WBV exposure occurred for 60s duration at a frequency of 45Hz and an amplitude of 2mm. The time interval between each of the five WBV exposures was 3 minutes and after each WBV exposure, the stimulation protocol was re-executed at 30 seconds post vibration. As an assessment of recovery the stimulation protocol was repeated 3, 5, 10, 20, 30 and 40 minutes post WBV. As well, subjects performed three plantar and three dorsi-flexion MVC six minutes into recovery.

Physiological Assessment

Force

Force data was obtained for the non-dominant left foot during the actions of plantar and dorsi flexion. Data was recorded using an MLP-150 linear calibrated force transducer (Transducer Techniques, Temecula, CA). Force signals were collected (Coulbourn, Allentown, Pennsylvania) and converted from an analog to digital format by a 16-bit 1401 plus A/D converter (CED, Cambridge, England) at a sampling rate of 500Hz. Peak force was calculated for plantar and dorsi-flexion MVC. The peak tension, rate of force development and rate of force decline were assessed (Spike 2 version 6.03, CED, Cambridge UK) for each involuntary twitch response elicited during the M-wave stimulation and the average of the three responses are reported for each time period in the protocol.

Surface EMG

Following skin preparation involving the removal of hair on the leg and the use of 70% isopropyl alcohol swabs and course skin pads to exfoliate the skin

(Webcol, Tyco Medical, Montreal, Quebec), 4mm Ag/AgCl recording electrodes were placed 2cm distal to the bifurcation of the gastrocnemius and directly over the achilles tendon with a ground on the lateral malleolus (Appendix C). Electrodes were also placed over the lateral gastrocnemius 10 cm distal to the popliteal fossa with an inter-electrode distance of 1cm and a reference on the patella. To assess the tibialis anterior, 4mm Ag/AgCl recording electrodes were placed 10 cm distal to the patella with an inter-electrode distance of 1cm. All electrodes and wires were secured with Hypafix (Hamburg, Germany), a dressing retention sheet to ensure stable contact during the experiment. EMG was amplified (1000x), band pass filtered (90Hz-1000Hz) and recorded to computer with analog to digital formatting (1401 plus, CED, Cambridge, England) for offline analysis. EMG data from the isometric squat during WBV was full wave rectified and the root mean square (RMS) calculated (Spike 2 version 6.03, CED, Cambridge UK) for the soleus, lateral gastrocnemius, and tibialis anterior during the isometric squats. All data was then normalized to the maximal EMG response associated with the MVC contractions.

The electrical measures from the H-reflex were characterized by evaluating the latency, duration, and peak to peak amplitude (Figure 9) and are reported as an average of the three elicited responses. The M-wave peak to peak amplitude was measured and the values reported are an average of the first three measures. H-reflex amplitude was defined as the peak to peak displacement from the most negative to positive point of the compound action potential. The measures were taken within the confines of two vertical cursors

placed at the beginning and end of the waveform. The M-wave was assessed through identical parameters and the latency of both waveforms was measured as the time between a cursor placed at the onset of the stimulation artifact and the onset of the H-reflex and M-wave respectively.

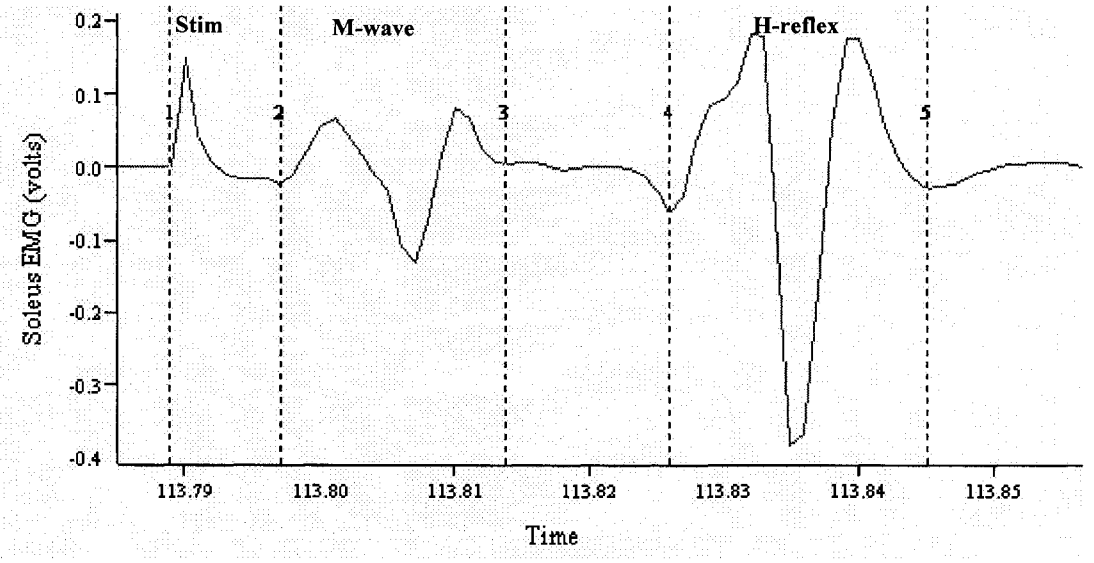

Figure 9. Representative M-wave and H-reflex analysis. The vertical cursor (1) on the left indicates the onset of stimulation represented by a stimulation artifact. Vertical cursor (2) indicates the onset of the M-wave, (3) indicates the end of the M-wave, (4) indicates the onset of the H-reflex, (5) indicates the end of the H-reflex. The vertical axis represents the waveform amplitude (volt) and the horizontal axis represents the time (s).

2.3 Statistical Analysis

A 2 (sex) x 13 (trials) repeated measures ANOVA was employed to evaluate the H-reflex, M-wave, and twitch contractile properties. For all assessments two baseline measures were initially included in the analysis. The first measure (Br) was the baseline values at rest prior to standing on the platform, whereas the second measure (Bs) corresponded to the baseline measures taken after standing on the platform without vibration. The dependent variables included the H-reflex properties of peak to peak amplitude, latency (time to waveform onset), M-wave peak to peak amplitude, submaximal M-wave

amplitude, M-wave duration and latency. As well, the twitch contractile properties of peak tension (PT), average rise of the twitch and the average fall. A 2 (sex) x 5 (isometric squat) repeated measures ANOVA was used to assess EMG activity during the isometric squats while on the vibration platform. For all statistical comparisons, an alpha level set to $p=0.05$ was utilized and post hoc Tukey's tests employed for significant interactions. Prior to and following the isometric squats; average MVC force, EMG, and percent activation were statistically analyzed using paired T-tests.

2.4 Results

The baseline measures were initially evaluated and the spinal reflex excitability measures of H-reflex ($p=0.44$) and M-wave ($p=0.52$) between B_R and B_S did not differ. As well, twitch contractile measures of peak tension ($p=0.14$), average rate of rise ($p=0.34$) and average rate of decline also did not differ between B_R and B_S. Thus, all comparisons between vibration and recovery were made to B_S. The 2 x 13 repeated measures ANOVA for submaximal M-wave amplitude was non-significant ($p=0.77$) and there were no main effects observed for trial ($p=0.26$) and sex ($p=0.21$). The non-significant changes confirmed that the intensity of electrical stimulation had not changed throughout the duration of the protocol as previously described by Alrowayeh et al., (2005).

2.5 Neuromuscular Measures in Response to WBV

Hoffmann Reflex

The 2 x 13 repeated measures ANOVA for peak to peak amplitude of the H-reflex was non significant ($p=0.30$) and because there was no main effect for

sex (p=0.48) but a main effect for trial (p<0.01), the data was collapsed across sex. Peak to peak amplitude of the first (p=0.01), second (p<0.01), third (p<0.01), fourth (p<0.01), and fifth (p<0.01) measures following WBV (Figure 10a) declined compared with B_S. The H-reflex during recovery was lower for the first (p=0.02), second (p=0.02), fifth (p=.024) and sixth (p=0.02) measures relative to Bs, but R3 (p=0.09) and R4 (p=0.06) did not differ from B_S. The data suggests H-reflex amplitude decreases as a consequence of acute WBV and does not recover within 40 minutes after the exposure (Figure 10).

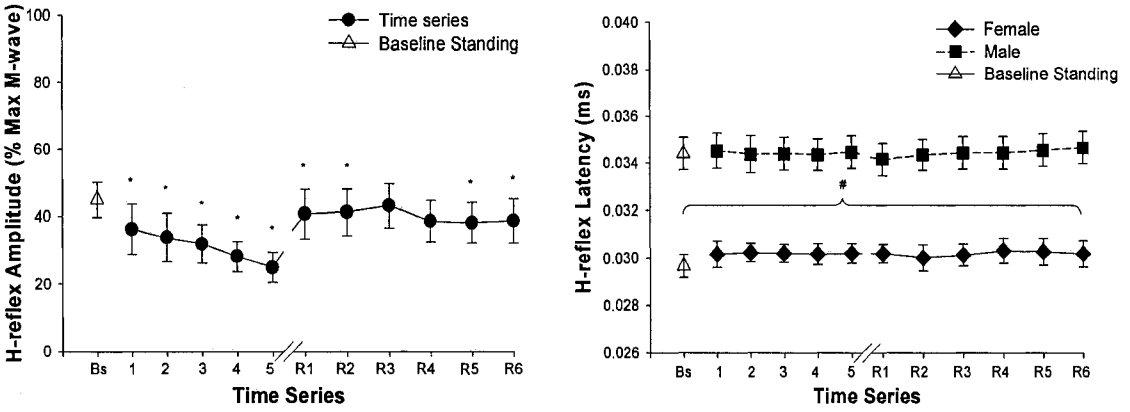

Figure 10. (a) H-reflex peak to peak amplitude (left). (b) H-reflex latency (right) for males and females. Horizontal axis represents each H-reflex for baseline, the 5 WBV exposures and the 6 recovery (R1-R6) measures made in the 40 minutes following WBV. The open triangles are the baseline (B_S) the filled circles are data for males and females, whereas the filled diamonds are females and the filled squares are males. *, Significant differences are relative to B_S at $p \leq 0.05$, # symbol represents significant difference between males and females ($p \leq 0.05$).

The repeated measures ANOVA of H-reflex latency (ms) exhibited no significant interaction (p=0.71), or main effect for trial (p=0.19), however a main effect was observed for sex (p<0.01). At B_S the males and females differed (p<0.01) and this difference was evident for the duration of acute WBV exposures and during the 40 minutes of recovery (Figure 10).

Compound Muscle Action Potential

The 2 x 13 repeated measures ANOVA for peak to peak amplitude of the maximal M-wave displayed no significant interaction ($p=0.64$). There was no main effect for sex ($p=0.88$), yet a main effect was present for trial ($p<0.01$). The M-wave peak to peak amplitude following WBV exposure did not differ significantly from B_S. However, a significant decrease in M-wave amplitude occurred at R1 ($p=0.04$), R2 ($p=0.04$), R3 ($p=0.02$), R4 ($p=0.01$), R5 ($p=0.02$) and R6 ($p=0.02$) relative to B_S (Figure 11a).

As a means to assess conduction velocity of the nerve, M-wave latency was evaluated as a means between sex and across trials with the 2 x 13 repeated measures ANOVA. There was no significant interaction ($p=0.91$) or main effect for sex ($p=0.27$), but a main effect of trial ($p=0.05$). The initial B_S value for M-wave latency did not differ for the WBV exposures or between R1-R5, but the latency was longer at R6 ($p=0.05$) relative to B_S (Figure 11b). M-wave duration

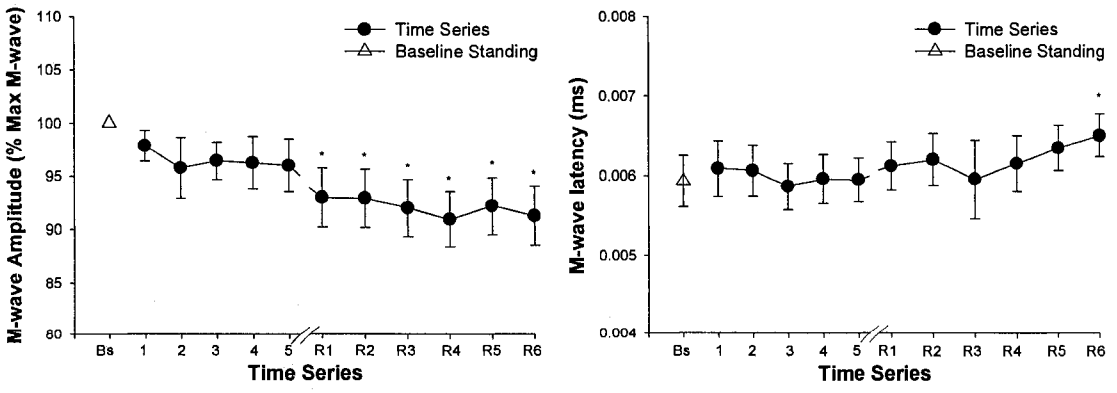

Figure 11. (a) M-wave peak amplitude (left) (b) M-wave latency (right) across trials for all subjects. Horizontal axis represents each M-wave following WBV 1-5 and during recovery R1-R6 for both graphs. Open plots are the baseline (B_S) whereas filled plots are the WBV exposure and recovery. *, Significant differences are relative to B_S at $p \leq 0.05$.

was also evaluated and there was a non-significant interaction (p=0.37), and main effects for trial (p=0.41) and sex (p=0.44). The H-reflex to M-wave ratio (H/M) when evaluated with the 2 x 13 repeated measures ANOVA was non significant (p=0.61), with no main effect for sex (p=0.56), but a main effect observed for trial (p=0.02). The peak H/M ratio for the third (p=0.02), fourth (p=0.03), and the fifth (p=0.01) measure following WBV exposure was less than Bs (Figure 12). However, for the entire 40 minutes following WBV the ratio did not differ from B_S to suggest an immediate return to pre WBV levels.

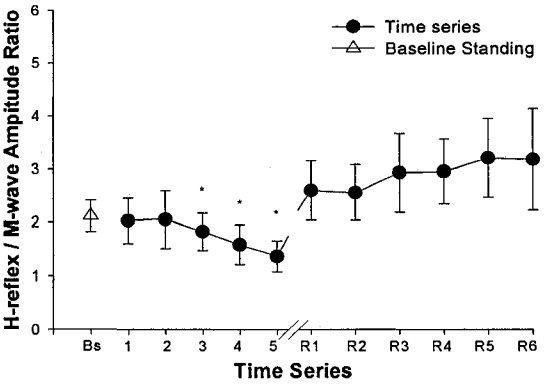

Figure 12. H-reflex to M-wave ratio across acute WBV and recovery. Horizontal axis represents the time series for baseline, the 5 WBV exposures and the 6 recovery (R1-R6) measures made in the 40 minutes following WBV. Open triangles are the baseline (B_S) whereas filled symbols are the WBV exposure and recovery. *, Significant differences are relative to B_S at $p \leq 0.05$.

Twitch Contractile Properties

Muscle function was evaluated through involuntary twitch contractile properties. The 2 x 13 repeated measures ANOVA interaction for peak tension was non-significant (p=0.19), but a main effect of trial was observed (p<0.01), while sex approached significance (p=0.056). Relative to B_S, there was a significant decrease in tension for the second (p=0.049), third (p<0.01), fourth (p=0.03) and fifth (p=0.02) measures following WBV exposure. Twitch tension

was also significantly less at R1 ($p<0.01$) and R2 ($p<0.01$) yet recovered by R3 ($p=0.58$) and subsequently fell at R5 ($p<0.01$) (Figure 13a).

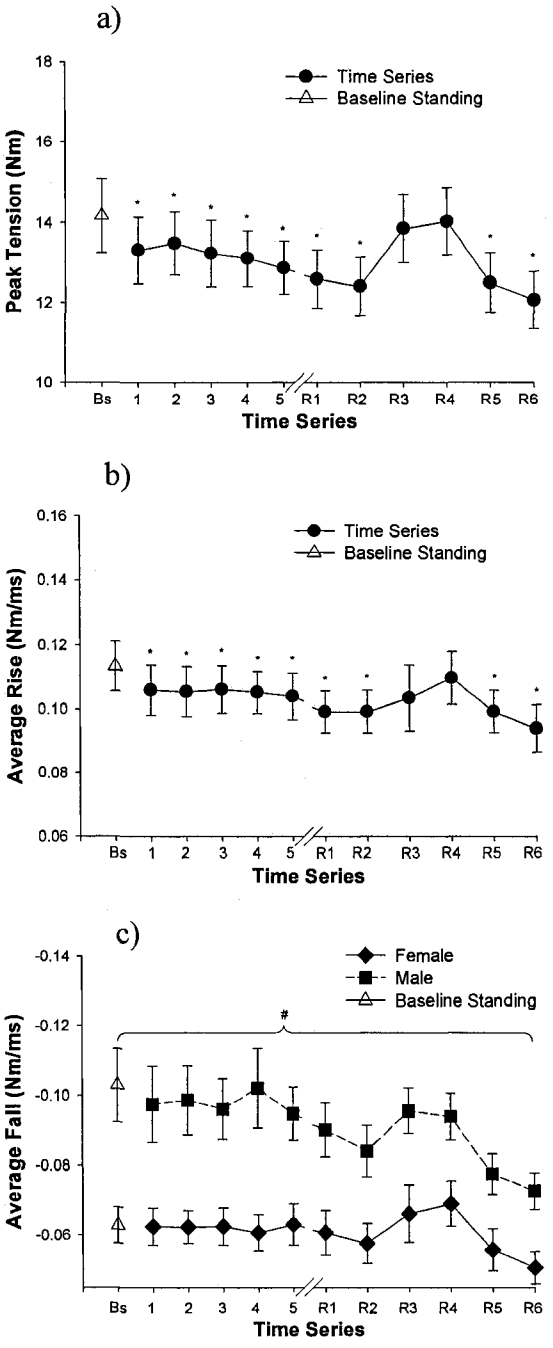

Figure 13. (a) Peak tension (PT) (b) Average rise and the (c) Average fall across trials. Horizontal axis represents each twitch following WBV 1-5 and during recovery R1-R6 for all graphs. The open triangles are the baseline (B_S) the filled circles are data for males and females, whereas the filled diamonds are females and the filled squares are males. *, Significant differences are relative to B_S at $p \leq 0.05$, # symbol represents significant difference between males and females ($p \leq 0.05$).

Rates of twitch contraction and relaxation were evaluated because twitch tension decreased, and this alteration influences contraction times. The 2-way interaction was non-significant for average rate of rise (AR) of the twitch ($p=0.47$) and there was no main effect for sex ($p=0.08$), but a main effect for trial ($p<0.01$) relative to the B_S. Similar to PT, the average rise of the twitch differed significantly from baseline following the first ($p=0.03$), second ($p<0.01$), third ($p=0.01$), fourth ($p=0.01$) and fifth ($p=0.01$) measure subsequent to WBV exposure. The average rate of contraction did not recover for R1 ($p<0.01$), R2 ($p<0.01$), R5 ($p=0.01$) and R6 ($p<0.01$) (Figure 13b). Thus, when the decrease in twitch amplitude was considered, contraction time of the twitch was slower and did not recover to baseline values 40min. after acute WBV. The interaction for the 2-way repeated measures ANOVA for rate of twitch relaxation was significant ($p=0.05$), and there was a main effect for sex ($p=0.01$), but no main effect for trial ($p=0.08$) (Figure 13c). Although rate of relaxation did not change over the course of WBV, there was a slowing of ~7.5% in males and ~0.5% in females. Twitch contractile measures demonstrate that for WBV peak tension decreases and rate of contraction slows, while rate of relaxation changes minimally, but more in males than females.

2.6 Muscle Activity and Force Assessment During WBV

Surface Electromyography

The 2 x 6 repeated measures ANOVA for the soleus EMGrms displayed no significant interaction ($p=0.42$); however, there was a significant main effect found for sex ($p=0.02$) and trial ($p<0.01$) relative to the initial control squat (C_S)

with no vibration. EMGrms increased for the first ($p<0.01$), second ($p<0.01$), third ($p<0.01$), fourth ($p<0.01$), and fifth ($p<0.01$) squat during the WBV exposure for males and females (Figure 13a). Soleus EMGrms for isometric squats during WBV increased ~ 6.7% for males and ~9.2% for females compared with the measure of no WBV.

The lateral gastrocnemius EMGrms 2 x 6 repeated measures ANOVA was non-significant ($p=0.71$) with no main effect for sex ($p=0.25$) but a significant main effect for trial ($p<0.01$). The EMGrms increased significantly for the first ($p<0.01$), second ($p<0.01$), third ($p=0.02$) and fourth ($p=0.05$) squat exercise performed during WBV exposure (Figure 13b) relative to the standing squat. During WBV exposure EMGrms of the lateral gastrocnemius increased similarly for males (~ 2.4%) and females (~3.0%).

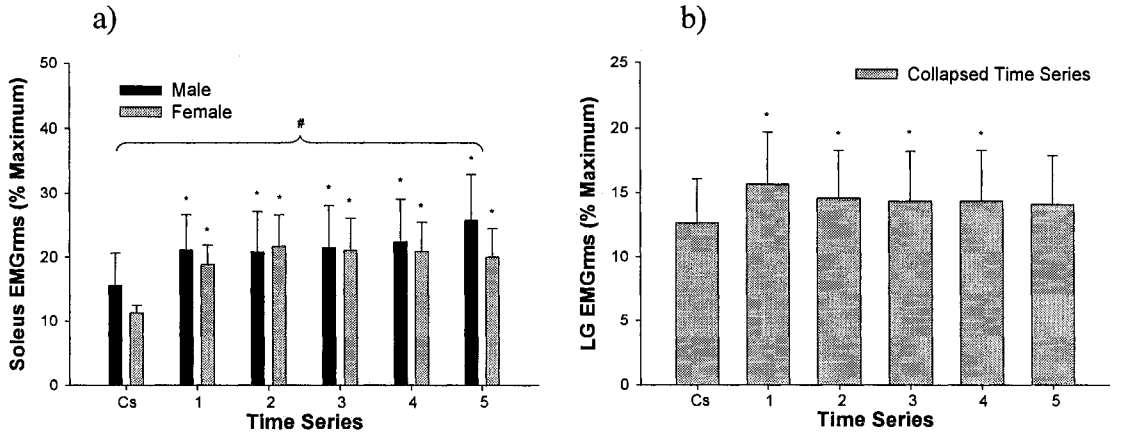

Figure 14. (a) Soleus EMGrms for males and females (b) Lateral gastrocnemius EMGrms across trials. The vertical axis represents EMG as a percentage of maximal EMG from the MVC. Horizontal axis represents EMGrms measured during C_S and WBV1-5. *, Significant differences relative to C_S and ($p \leq 0.05$). Horizontal brace (a) indicates significant difference between sex (#).

Performance Assessment

Maximal activation of the plantar flexor muscles pre (98.3% ± 0.012) and post (98.0% ± 0.027) WBV was attained for males and for females (97.4% ±

0.023; 96.3% ± 0.037). In a situation where maximal isometric performance is ensured to be near maximal and consistent prior to and following WBV, there was no significant increase in plantar flexion MVC in males and females as a consequence of WBV exposure. However, for both pre ($p=0.05$) and post ($p<0.01$) plantar flexion MVC performance, males were stronger than females (Figure 14a). MVC prior to WBV was 22% greater in the male subjects relative to females, and following WBV the sex-difference in MVC strength increased to 34%. However, surface EMG corresponding to the MVC measure prior to and following WBV exposure did not differ between males and females (Figure 14c).

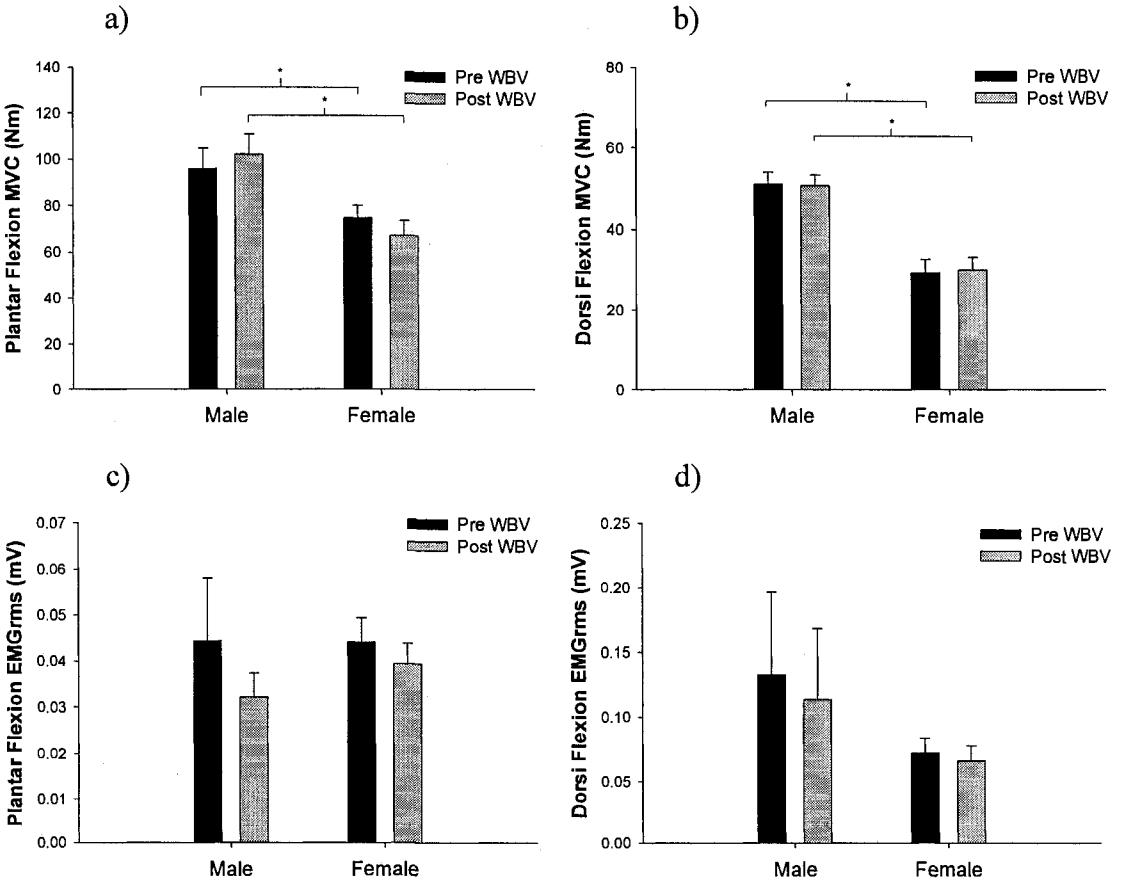

Figure 15. (a) Plantar flexion MVC force (b) Dorsi flexion MVC force (c) Plantar flexion EMG (d) Dorsi flexion EMG prior to and after WBV between sexes. *, Significant difference between males and females ($p \leq 0.05$).

Dorsi flexion MVC was not ascertained with the twitch interpolation technique, but isometric strength did not increase as a result of WBV exposure. Similar to the plantar flexors, males were stronger prior to ($p<0.01$) and following ($p<0.01$) WBV by an average of 43% and 41%, respectively (Figure 14b). Similar to plantar flexion, surface EMG did not change as a result of WBV exposure or differ between sex (Figure 14d).

2.7 Discussion

It has been reported that WBV exposure results in an enhancement of dynamic physical performance measures and muscle activity increases relative to conditions without vibration (Bosco et al., 1999a; Bosco et al., 1999b; Cochrane et al., 2004; Cochrane & Stannard, 2005; Hazell et al. 2007; Rittweger et al., 2003; Roelants et al., 2004b). However, no study has directly evaluated the mechanisms responsible for these increases associated with WBV. The results from this study extends the WBV literature to indicate that as a consequence of five, one-minute bouts of WBV: 1) H-reflex amplitude measured in the soleus muscle decreases sequentially following each vibration exposure and does not recover in the subsequent 40-minute time period; 2) M-wave amplitude does not decline during the WBV period, but during the subsequent 40-minute recovery period there is a gradual decrease in amplitude; 3) involuntary isometric twitch contractile tension associated with supramaximal stimulation decreases and the rate of contraction slows as a consequence of acute WBV and neither recover 40-minutes after vibration; 4) surface EMG of the soleus and lateral gastrocnemius increases during WBV confirming previous

studies of enhanced muscle activity; 5) isometric dorsi- and plantar-flexion muscle strength is not influenced by acute WBV. These H-reflex and twitch contractile measures suggest that WBV likely influences presynaptic inhibition altering spinal reflex excitability, and at the level of the muscle Ca^{2+} kinetics are slowed.

Neuromuscular Measures

Hoffmann Reflex

H-reflex amplitude is often utilized as a means of studying task related and or stimulus induced changes in human motoneuronal excitability (Schieppati, 1987) and is often employed to assess the response of isolated tendon vibration. The physiological response to WBV has been proposed to be congruent to the effect of tendon vibration (Cardinale & Bosco, 2003) but has never been directly quantified. Results from this study are the first to measure and quantify a decline in the H-reflex amplitude as a result of WBV. The ~50% decrease in H-reflex amplitude in the soleus following five bouts of acute WBV is similar to the effect observed following direct tendon vibration (Martin, Roll & Gauthier, 1986; Desmedt & Godaux 1978) where an increase and decrease in H-reflex amplitude has been associated with motor unit recruitment and de-recruitment, respectively (Desmedt & Godaux, 1978). Thus, the decline in H-reflex amplitude observed in this study as a consequence of WBV is likely associated with the derecruitment of motor units.

A number of studies have observed an increase in physical performance following WBV (Bosco et al., 1999a; Bosco et al., 1999b; Cochrane et al., 2004;

Cochrane & Stannard, 2005; Rittweger et al., 2003; Roelants et al., 2004) and enhanced spinal reflex excitability has been proposed to contribute to these performance benefits (Cardinale & Lim, 2003). Data from this study of acute WBV indicates that spinal reflex excitability is not enhanced, rather depressed. The decline in H-reflex observed following tendon vibration has been accredited to inhibitory 1a afferent feedback which contributes to presynaptic inhibition (Desmedt & Godaux, 1978; Iles & Roberts, 1985; Martin et al., 1986; Romaiguere, Vedel & Pagni, 1993). In the context of the soleus and WBV 1a afferent feedback is likely increased because the vibration platform results in rapid changes in muscle length and in-turn spindle sensitivity. These rapid changes may result in a barrage of input from the sensory organs of agonist and antagonist muscles which induce presynaptic inhibition due to excessive afferent feedback. Research has elucidated that the principle cause of presynaptic inhibition is a product of primary afferent depolarization produced by axo-axonic GABAergic synapses and the subsequent release of inhibitory neurotransmitters (Rudomin & Schmidt, 1999). Thus, the increase in afferent feedback with WBV may potentiate the release of glutamate, a strong inhibitory neurotransmitter, and in-turn reduces alpha motor neuron activity as indicated by the decline in H-reflex amplitude. The non-significant change in H-reflex latency suggests that the changes in spinal excitability as evidence in amplitude adaptations are not influenced by conduction velocity.

Compound Muscle Action Potential

M-wave amplitude, described in the literature as an overall measure of muscle activation (Tucker, Tuncer & Turker, 2005), did not change following repeated WBV exposure. However, M-wave amplitude was significantly less over the course of the 40 minute recovery period to exhibit a latent depression following acute WBV. Muscle excitability consequent to fatiguing exercise has been shown to change as a result of alterations in the ionic process of the Na^+-K^+ pump and Na^+-K^+ gradient (Lepers, Maffiuletti, Rochette, Brugniaux & Millet, 2002). As a result, there has been an observed decrease in M-wave root mean square within the vastus lateralis muscle during exercise and up to 30 minutes following (Lepers et al., 2002). The inhibitory influence on M-wave amplitude due to an acute WBV bout can be described as a significant one. M-wave amplitude following the MVC during recovery remained depressed relative to the baseline, whereas a prior study conducted by Hicks, Fenton, Garner & McComas (1989) characterized a significant potentiation of the M-wave following MVC upwards of ~50%. As well, the submaximal M-wave immediately preceding the H-reflex displayed no significant changes in amplitude during the WBV and recovery protocol establishing consistency of stimulation intensity. As a result, any changes in the H-reflex amplitude are the consequence of test conditions other than stimulation intensity when M-wave amplitude is constant (Tucker et al., 2005).

Twitch Contractile Properties

In order to evaluate the effect of WBV on contractile activity, involuntary twitch contractile properties were also evaluated. Peak twitch tension decreased after the first WBV bout and declined over the succeeding acute exposures and did not recover in the 40 minutes following. There was also a parallel decrease in the rate of force development but no change in rate of relaxation. These observations suggest that intracellular Ca^{2+} release may be influenced by WBV. Peak tension and the rate of force development has been observed to be depressed following exhaustive exercise as a result of reduced Ca^{2+} reuptake and enzyme activity; however, relaxation time remains unaffected (Booth, McKenna, Ruell, Gwinn, Davis, Thompson, Harmer, Hunter & Sutton, 1997; Lepers et al., 2002) similar to the rate of force decline following WBV. As well, contractile activity remained depressed up to 60 minutes following exhaustive exercise (Booth et al., 1997), as was found with WBV following 40 minutes of recovery. The role of Ca^{2+} extrapolated from twitch contractile properties provides insight into the function of excitation contraction coupling with WBV exposure.

Muscle Activity and Force Assessment

Surface Electromyography

Muscle activity has been reported to increase during WBV (Bosco et al. 1999a; Cardinale & Lim, 2003; Delecluse et al., 2003; Hazell, Jakobi & Kenno, 2007; Rittweger et al. 2003; Torvinen et al. 2002a,b) and the EMG data from the soleus and lateral gastrocnemius during five, one minute periods of acute WBV

support these observation. However, this is the first study to compare EMG activity during WBV between men and women. The average increase in EMGrms of the soleus in females was ~9.2% and in males was ~6.7%, whereas the increase in the lateral gastrocnemius was ~3.0% for females and ~2.4% for males. The significant increase in soleus EMG of men was statistically less than women, but similar to prior reports of an increase of ~6.7% in the quadriceps of males following WBV at 45Hz and 2mm (Hazell et al. 2007). To our knowledge sex-related differences in EMG have not been observed following WBV. Sex-related differences in EMG activity have been observed during fatigue and following immobilization (Hunter & Enoka, 2001; Semmler, Kutzscher & Enoka, 1999) and have been attributed to differential rates of fatigue between males and females. Although WBV results in differential increases in EMG there was no prolonged influence on performance or reflex activity in this study.

Increases in EMGrms have been attributed to a variety of different mechanisms including the enhancement of alpha motor neuron recruitment, discharge rate or synchronization; however, these mechanisms remain unsubstantiated via experimental research (Cardinale & Lim, 2003). An increase in motor unit recruitment or discharge rate would seem an unlikely response in this study because the H-reflex amplitude declined which suggests orderly derecruitment of motor units. Alternatively, a more probable response contributing to the increases in muscle activity would be the synchronization of motor units during WBV exposure. Motor unit synchronization has been demonstrated to augment the surface EMG signal (Farina, Merletti & Enoka,

2003) but exert no effect on force production (Enoka & Fuglevand, 2001). There was no increase in isometric plantar or dorsi-flexion force in this study.

Performance Assessment

Performance changes have been documented following WBV exposure through a variety of dynamic performance measures (Cochrane & Stannard, 2005; Roelants et al., 2004a,b; Rittweger et al., 2003) However, all previous attempts to characterize the performance benefit have not incorporated a method to ensure that the effort exerted prior to vibration was similar to the post vibration condition. Utilization of the twitch interpolation technique enables quantification of maximal effort prior to and following WBV. When the attempt and isometric MVC is near maximal but equivalent between conditions WBV does not enhance isometric plantar flexion and dorsi flexion MVC. Furthermore, the corresponding MVC EMGrms amplitude did not differ prior to or following WBV for males or females suggesting that the amount of muscle activity which necessitates the force produced is not influenced by WBV.

2.8 Conclusion

This study is the first to quantify spinal reflex activity and contractile function subsequent to acute WBV administered at 45Hz and 2mm. The significant depression of H-reflex amplitude in combination with the decline in twitch tension and slowing of twitch contraction rate suggests that WBV likely alters spinal reflex excitability and muscle contractility. The H-reflex data indicates that 1a afferent feedback induces presynaptic inhibition on the alpha motor neuron pool. Whereas, the twitch contractile data suggests that as a

consequence of WBV intracellular SR Ca^{2+} release is depressed. These changes were observed in acute WBV where isometric contractile strength did not increase. Thus, acute WBV does not benefit isometric strength in conditions where pre-synaptic inhibition is increased and Ca^{2+} kinetics slowed. Future studies should consider assessing spinal and contractile activity in conjunction with standard dynamic physical performance.

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Chapter III

Conclusion and Future Directions

3.0 Conclusion

Recent studies have speculated that WBV results in an increase in spinal reflex excitability (Cardinale & Lim, 2003), a proposed mechanism for increased muscle activity and performance measures. However, the current data suggests otherwise and that further research is necessary to elucidate the underlying mechanisms. The present data suggests that presynaptic inhibition exhibits a large influence following WBV exposure and the corresponding parameters of the H-reflex, M-wave and twitch contractile properties. H-reflex amplitude was observed to decrease as well as M-wave amplitude and the associated twitch contractile properties. As previously shown, an overall increase in muscle activity during WBV exposure (Bosco et al. 1999a; Cardinale & Lim, 2003; Delecluse et al., 2003; Hazell et al., 2007; Rittweger et al. 2003; Torvinen et al. 2002a,b) has been observed once again in the soleus and lateral gastrocnemius. There was no change however in performance of the triceps surae or tibialis anterior during plantar or dorsi flexion respectively. These data suggest that WBV exposure results in the inhibitory effect on the motor unit pool and twitch contractile properties as described by the decrease in H-reflex and M-wave amplitude as well as the peak tension and average rise of the twitch.

3.1 Limitations and Future Directions

Limitations

The H-reflex has been characterized in a variety of different muscles. However, the soleus muscle has been predominantly used in past research as a result of convenience and reliability. The current study was based on the assumption that the soleus muscle was a representative model of global skeletal muscle activity in response to WBV exposure. It was utilized due to the large ratio between afferent and efferent neuron size (Schieppati, 1987) and the accessibility of stimulation (Hopkins et al., 2001) in order to evoke the H-reflex response effectively. Subsequently, muscles of the quadriceps femoris may provide a more representative outlook as to the effect of WBV exposure due to a more significant contribution with respect to the isometric squat.

It has been suggested however that H-reflex amplitude has a variety of limitations with respect to the assessment of spinal reflex excitability. H-reflex amplitude is subject to change from the potential influence of presynaptic, reciprocal, autogenic, and recurrent inhibition associated with complex neural circuitry if not properly controlled for (Misiaszek, 2003). The current study carefully maintained a static posture during the stimulation protocol through confinement of the non-dominant leg in a set apparatus with velcro straps. Subjects were however predisposed to environmental sensory factors within the laboratory which may have had an influence over the H-reflex measures.

The isometric squat was chosen based on the assumption that it would elicit significant increases in muscle activity within the lower leg. As a result, the

soleus muscle was in a relatively neutral position throughout the protocol during the squat while exhibiting an increase in muscle activity. Although the soleus was investigated, the muscles of the quadriceps femoris are the primary contributors associated with the isometric squat and may have been influenced to a greater extent following WBV exposure. Consequently, the relative contribution and activation of the soleus muscle during the squat exercise may have been minimal with respect to the exercise.

Future Directions

Further research is necessary in order to measure the neuromuscular effect of WBV exposure at the frequencies of 25, 30, 35, 40, and 45Hz corresponding to both 2mm and 4mm plate deflection respectively. A variety of different muscles need to be studied including those more functionally associated with MVC performance measures in order to support past findings of enhanced performance in the vertical jump or the present data with respect to isometric strength. Dynamic WBV exercise protocols should be explored further in order to understand the associated neuromuscular changes relative to isometric postures. As well, males and females in their seventh decade having undergone the age related changes of sarcopenia and motor unit remodeling need to be studied to assess the potential implications of WBV exercise for an older population.

In order to achieve a greater understanding of the mechanisms related to the effect of WBV, future studies must quantify the response of motor unit properties during and following exposure with indwelling electrodes. The relationship between WBV and motor unit recruitment needs to be established in

order to replicate the findings of Desmedt & Godaux (1978) to confirm the presence of orderly de-recruitment. Increases in EMG amplitude observed in prior studies have been speculated to be a result of enhanced synergist recruitment patterns and motor unit synchronization (Cardinale & Lim, 2003). The synchronization of motor units requires further consideration through motor unit assessment in order to evaluate the potential contribution to the increase in EMG amplitude.

APPENDICES

APPENDIX A

Consent Form

UNIVERSITY OF WINDSOR

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Neuromuscular Response of the Soleus following Whole Body Vibration as characterized by the Hoffmann Reflex**

You are asked to participate in a research study conducted by **a student investigator: Jonathan Scherer and advisor: Dr. Kenji Kenno** from the **Department of Kinesiology, Faculty of Human Kinetics (x2473)** at the University of Windsor. The results of this study will contribute to Jonathan Scherer's thesis project to complete the candidacy for a Masters of Human Kinetics degree.

If you have any questions or concerns about the research, please feel free to contact the student investigator

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Tel. (519) 253-3000 ext. 4049
E-mail: schere4@uwindsor.ca

PURPOSE OF THE STUDY

The goal of this study is to quantify the neuromuscular response of a static squat posture following whole body vibration.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:
-Volunteer approximately two hours of your time during one visit to the lab.

-Visit includes familiarization, a series of contractions, and direct nerve stimulation, neuromuscular data collection, and whole body vibration training.
-Perform both strong and weak contractions accompanied by stimulation of the lower leg.

POTENTIAL RISKS AND DISCOMFORTS

A possible risk associated with the use whole body vibration is a feeling of discomfort and nausea. This risk will be minimized through the use of a familiarization period prior to data collection. To-date in the lab., and other labs that utilize this technique there have been minimal reports.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will not receive monetary gain from participation. But you will benefit from experiencing whole body vibration and neuromuscular tests, in order to better understand a new training technique.

PAYMENT FOR PARTICIPATION

Subjects will not receive payment for their participation within this study.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. All data from subjects will be collected and coded for anonymity at the beginning of each study session.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so. Any persons with musculoskeletal disorders, injury, other neurological disorders or painful neuropathy, myopathy, severe cardiovascular disease, have a pacemaker, recovering from surgery, alcoholism, pregnancy, or extreme physical activity patterns are unsuitable candidates for this study and will be excluded.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

Upon completion of data collection, individual contact information will be recorded for future notification. Results from the study will be available on Dr. Kenji Kenno's web site, or by mail. If you would like a copy of the paper mailed to you, please provide mailing information.

http://web4.uwindsor.ca/units/hk/deptKinesiology.nsf/main/ADF9B73E8B85A87485256E4800259D6A?OpenDocument

SUBSEQUENT USE OF DATA

This data will / will not be used in subsequent studies.

Do you give consent for the subsequent use of the data from this study
☐ Yes ☐ No

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; telephone: 519-253-3000, ext. 3916; e-mail: lbunn@uwindsor.ca.

SIGNATURE OF RESEARCH SUBJECT/LEGAL REPRESENTATIVE

I understand the information provided for the study **Neuromuscular Response of the Soleus following Whole Body Vibration as characterized by the Hoffmann Reflex** as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

_____
Name of Subject

_____
Signature of Subject Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____
Signature of Investigator Date

UNIVERSITY OF
WINDSOR

LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Neuromuscular Response of the Soleus following Whole Body Vibration as characterized by the Hoffmann Reflex**

You are asked to participate in a research study conducted by **a student investigator: Jonathan Scherer and advisor: Dr. Kenji Kenno,** from the **Department of Kinesiology, Faculty of Human Kinetics** at the University of Windsor. **The results of this study will contribute to Jonathan Scherer's thesis project to complete the candidacy for Masters of Human Kinetics degree.**

If you have any questions or concerns about the research, please feel free to contact the student investigator

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The goal of this study is to quantify the neuromuscular response of a static squat posture following whole body vibration.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:
-Volunteer approximately two hours of your time during one visit to the lab.
-Visit includes familiarization, a series of contractions, and direct nerve stimulation, neuromuscular data collection, and whole body vibration training.

-Perform both strong and weak contractions accompanied by stimulation of the lower leg.

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A possible risk associated with the use whole body vibration is a feeling of discomfort and nausea. This risk will be minimized through the use of a familiarization period prior to data collection. To-date in the lab., and other labs that utilize this technique there have been minimal reports.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will not receive monetary gain from participation. But you will benefit from experiencing whole body vibration and neuromuscular tests, in order to better understand a new training technique.

.

PAYMENT FOR PARTICIPATION

Subjects will not receive payment for their participation within this study.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. All data from subjects will be collected and coded for anonymity at the beginning of each study session.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so. Any persons with musculoskeletal disorders, injury, other neurological disorders or painful neuropathy, myopathy, sever cardiovascular disease, have a pacemaker, recovering from surgery, alcoholism, pregnancy, or extreme physical activity patterns are unsuitable candidates for this study and will be excluded.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

Upon completion of data collection, individual contact information will be recorded for future notification. Results from the study will be available on Dr. Kenji Kenno's web site, or by mail. If you would like a copy of the paper mailed to you, please provide mailing information.
http://web4.uwindsor.ca/units/hk/deptKinesiology.nsf/main/ADF9B73E8B85A874
85256E4800259D6A?OpenDocument

SUBSEQUENT USE OF DATA

This data will / will not be used in subsequent studies.

Do you give consent for the subsequent use of the data from this study?
☐ Yes ☐ No

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario N9B 3P4; telephone: 519-253-3000, ext. 3916; e-mail: lbunn@uwindsor.ca.

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____

Signature of Investigator Date

APPENDIX B

UNIVERSITY OF
WINDSOR
OFFICE OF THE
RESEARCH ETHICS BOARD

Today's Date:	March 29, 2007
Principal Investigator:	Mr. Jonathan Scherer
Department/School:	Kinesiology
REB Number:	06-267
Research Project Title:	"Neuromuscular Response of the Soleus Following Whole Body Vibration as Characterized by the Hoffman Reflex"
Clearance Date:	March 29, 2007
Project End Date:	December 31, 2007
Progress Report Due:	August 30, 2007
Final Report Due:	December 31, 2007

This is to inform you that the University of Windsor Research Ethics Board (REB), which is organized and operated according to the *Tri-Council Policy Statement* and the University of Windsor *Guidelines for Research Involving Human Subjects*, has granted approval to your research project on the date noted above. This approval is valid only until the Project End Date.

A Progress Report or Final Report is due by the date noted above. The REB may ask for monitoring information at some time during the project's approval period.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the REB. Minor change(s) in ongoing studies will be considered when submitted on the Request to Revise form.

Investigators must also report promptly to the REB:
a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

Forms for submissions, notifications, or changes are available on the REB website: www.uwindsor.ca/reb. If your data is going to be used for another project, it is necessary to submit another application to the REB.

We wish you every success in your research.

Maureen Muldoon

Maureen Muldoon, Ph.D.
Chair, Research Ethics Board

cc: Dr. Jennifer Jakobi, Kinesiology
Research Ethics Coordinator

This is an official document. Please retain the original in your files.

APPENDIX C

Electrode Placement

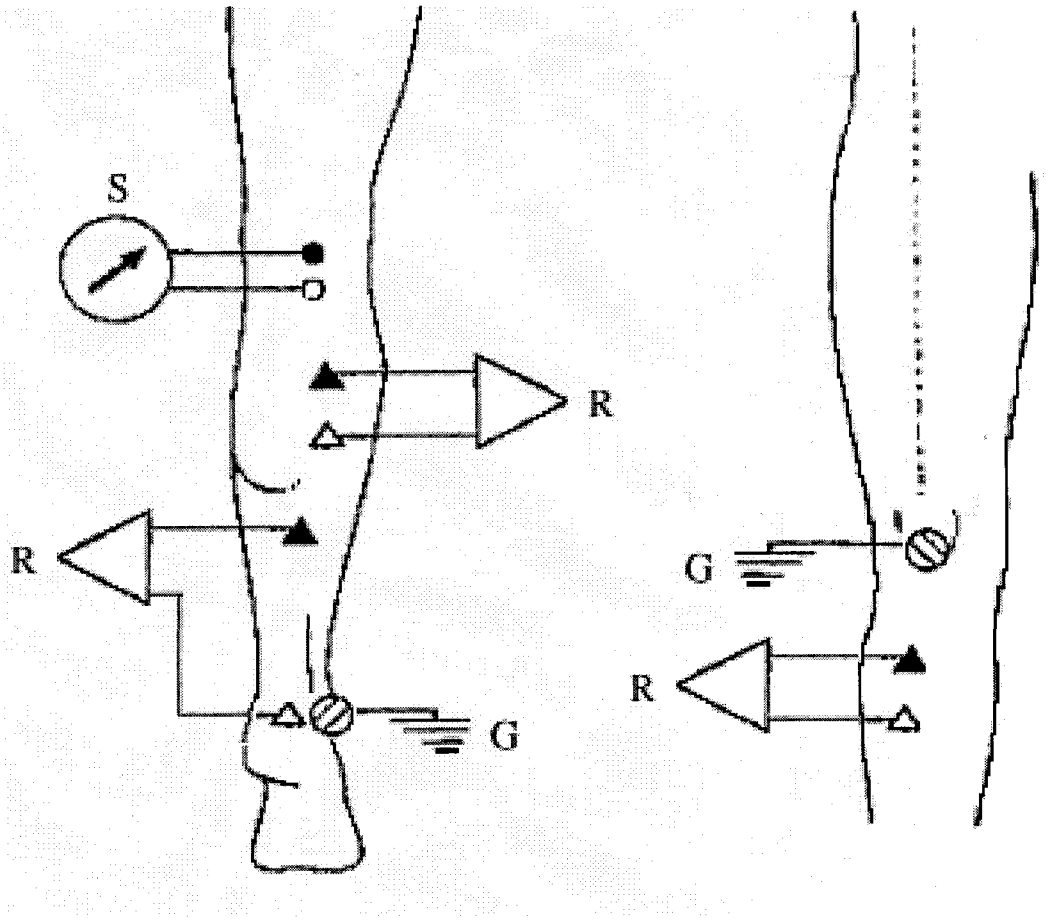


Figure: Posterior non dominant leg (left) and anterior non dominant leg (right). Electrode placement corresponds to the idealized setup in order to evoke the H-reflex and M-wave from the soleus (left; monopolar configuration) as well as global muscle activity from the lateral gastrocnemius (left; bipolar configuration) and tibialis anterior (right; bipolar configuration) (Figure adapted from Alrowayeh et al., 2003).

APPENDIX D

Waveform Analysis

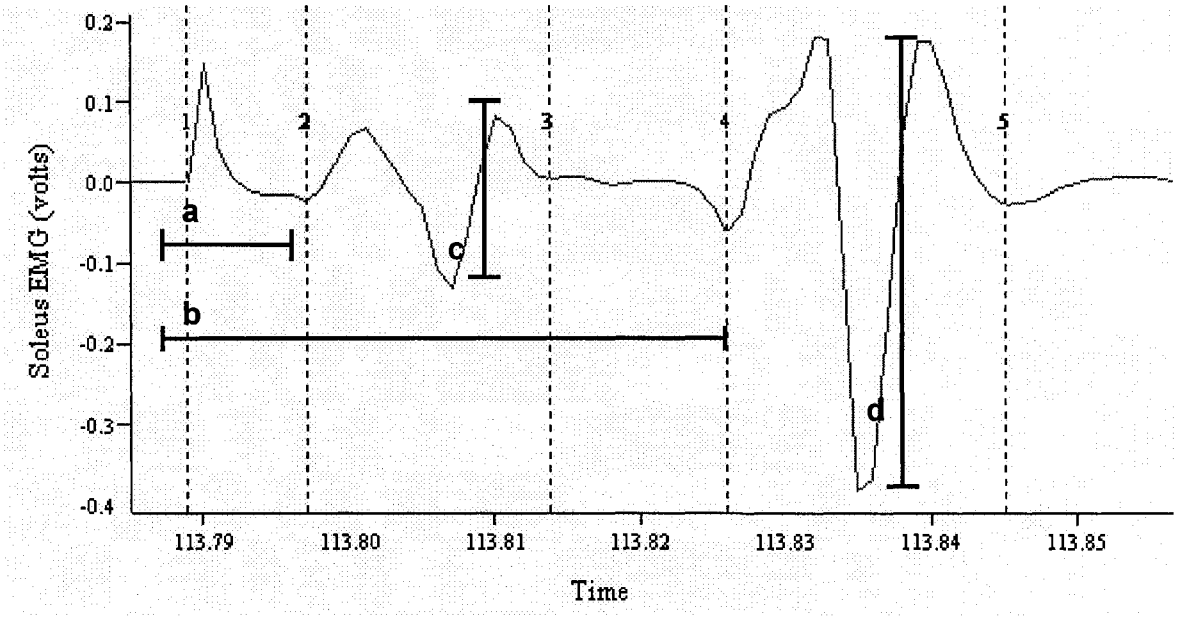
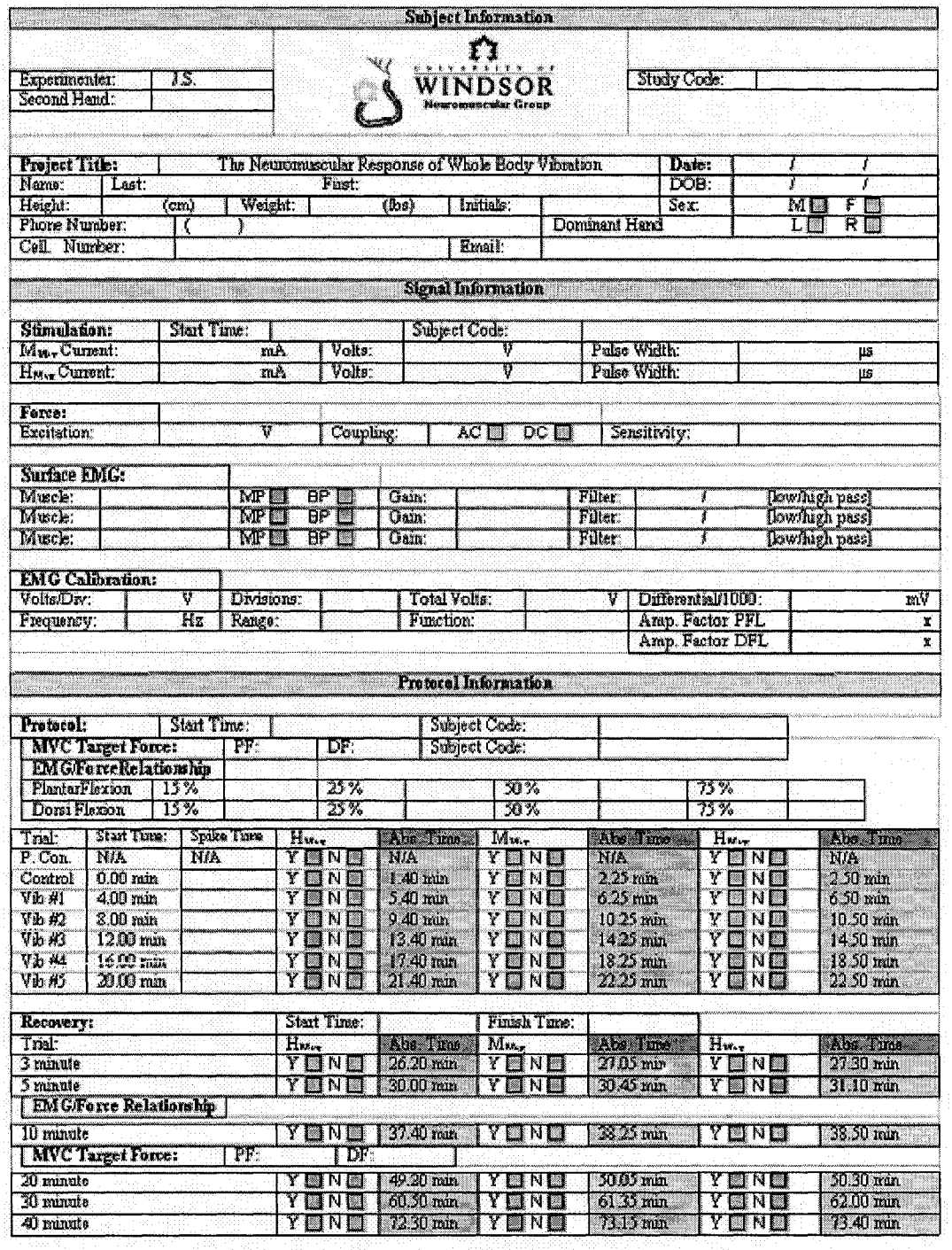


Figure: Waveform parameters corresponding to signal analysis. (a) M-wave latency indicating the time from stimulation to onset of waveform; (b) H-reflex latency indicating the time from stimulation to onset of waveform; (c) submaximal M-wave amplitude indicating peak to peak waveform displacement; (d) H-reflex amplitude indicating peak to peak waveform displacement; H/M ratio corresponds to (d)/(c).

APPENDIX E

Data Sheet



Subject Information

Experimenter:	J.S.	Study Code:	
Second Hand.:			

UNIVERSITY OF WINDSOR Neuromuscular Group

Project Title:	The Neuromuscular Response of Whole Body Vibration					**Date:**	/ /
Name:	Last:	First:				DOB:	/ /
Height:	(cm)	Weight:	(lbs)	Initials:		Sex:	M ☐ F ☐
Phone Number:	( )			Dominant Hand			L ☐ R ☐
Cell. Number:			Email:				

Signal Information

Stimulation:	Start Time:		Subject Code:		
M_{max} Current:	mA	Volts:	V	Pulse Width:	μs
H_{max} Current:	mA	Volts:	V	Pulse Width:	μs

Force:					
Excitation:	V	Coupling:	AC ☐ DC ☐	Sensitivity:	

Surface EMG:								
Muscle:		MP ☐	BP ☐	Gain:		Filter:	/	[low/high pass]
Muscle:		MP ☐	BP ☐	Gain:		Filter:	/	[low/high pass]
Muscle:		MP ☐	BP ☐	Gain:		Filter:	/	[low/high pass]

EMG Calibration:							
Volts/Div:	V	Divisions:		Total Volts:	V	Differential/1000:	mV
Frequency:	Hz	Range:		Function:		Amp. Factor PFL	x
						Amp. Factor DFL	x

Protocol Information

Protocol:	Start Time:		Subject Code:		
MVC Target Force:	PF:	DF:	Subject Code:		

EMG/Force Relationship								
PlantarFlexion	15%		25%		50%		75%	
Dorsi Flexion	15%		25%		50%		75%	

Trial:	Start Time:	Spike Time	H_{max}	Abs. Time	M_{max}	Abs. Time	H_{max}	Abs. Time
P. Con.	N/A	N/A	Y ☐ N ☐	N/A	Y ☐ N ☐	N/A	Y ☐ N ☐	N/A
Control	0.00 min		Y ☐ N ☐	1.40 min	Y ☐ N ☐	2.25 min	Y ☐ N ☐	2.50 min
Vib #1	4.00 min		Y ☐ N ☐	5.40 min	Y ☐ N ☐	6.25 min	Y ☐ N ☐	6.50 min
Vib #2	8.00 min		Y ☐ N ☐	9.40 min	Y ☐ N ☐	10.25 min	Y ☐ N ☐	10.50 min
Vib #3	12.00 min		Y ☐ N ☐	13.40 min	Y ☐ N ☐	14.25 min	Y ☐ N ☐	14.50 min
Vib #4	16.00 min		Y ☐ N ☐	17.40 min	Y ☐ N ☐	18.25 min	Y ☐ N ☐	18.50 min
Vib #5	20.00 min		Y ☐ N ☐	21.40 min	Y ☐ N ☐	22.25 min	Y ☐ N ☐	22.50 min

Recovery:	Start Time:		Finish Time:			
Trial:	H_{max}	Abs. Time	M_{max}	Abs. Time	H_{max}	Abs. Time
3 minute	Y ☐ N ☐	26.20 min	Y ☐ N ☐	27.05 min	Y ☐ N ☐	27.30 min
5 minute	Y ☐ N ☐	30.00 min	Y ☐ N ☐	30.45 min	Y ☐ N ☐	31.10 min
EMG/Force Relationship						
10 minute	Y ☐ N ☐	37.40 min	Y ☐ N ☐	38.25 min	Y ☐ N ☐	38.50 min
MVC Target Force:	PF:	DF:				
20 minute	Y ☐ N ☐	49.20 min	Y ☐ N ☐	50.05 min	Y ☐ N ☐	50.30 min
30 minute	Y ☐ N ☐	60.50 min	Y ☐ N ☐	61.35 min	Y ☐ N ☐	62.00 min
40 minute	Y ☐ N ☐	72.30 min	Y ☐ N ☐	73.15 min	Y ☐ N ☐	73.40 min

VITA AUCTORIS

Jonathan Scherer

EDUCATION

University of Windsor, Windsor, ON
M.H.K. Applied Human Performance, In Progress **January 2008**
Thesis: "The Neuromuscular Response of the Soleus following Whole Body Vibration as Characterized by the Hoffmann Reflex"
University of Windsor, Windsor, ON
B.H.K. Honours Human Kinetics **June 2005**
Areas of Concentration: Neuromuscular physiology, Surface Electromyography, Whole Body Vibration
Independent Study Project: Assessment of Practice: Performing Maximal Contractions in Young and Old Adults.

AWARDS

- Post-Graduate Tuition Scholarship, University of Windsor **2005-2007**
- Graduate Alumni Award, University of Windsor **2007**

TEACHING EXPERIENCE

University of Windsor, Windsor, ON
Graduate Assistant – Exercise Physiology **2005-2007**
Fielded inquiries, lab coordinator, assignment and exam marking

Graduate Assistant – Cardiac Physiology **2006**
Fielded inquiries, special tutorial sessions, assignment and exam marking

PRESENTATIONS

American College of Sports Medicine Annual Meeting, New Orleans, LA
Assessment of practice: performing maximal contractions in young and old adults: 1665: Board #164 May 30 2:00 PM – 3:30 PM **2007**
Medicine & Science in Sports & Exercise. 39(5) Supplement:S270, May 2007.
Scherer, Jon A., Edwards, Darl L., Jakobi, Jennifer M.

Ontario Exercise Physiology Conference, Barrie, ON
Determining the effect of a whole body vibration stimulus on muscles of the upper and lower body during dynamic contractions **2007**
Scherer, Jon A., Jakobi, Jennifer M., Kenji, Kenno A.

Canadian Society for Exercise Physiology Annual Scientific Meeting, London, ON
Neuromuscular response of the soleus following whole body vibration **2007**
Scherer, Jon A., Brown, Ruthie A., Kenji, Kenno A., Jakobi, Jennifer M.

MEMBERSHIPS AND EXTRACURRICULAR

- Canadian Society for Exercise Physiology
- Ontario Bodybuilding Association (OBA) Level 1 competitor